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ABSTRACT: Supplementing CP and propionate salts (**PS**) may improve economic returns in young range beef cows by increasing the dietary supply of glucogenic precursors. A 3-yr study conducted at Corona Range and Livestock Research Center from February to mid-July in 2005 (n = 80), 2006 (n = 81), and 2007 (n = 80) evaluated days to first estrus, calf weaning weight, BW change, and metabolic responses in 2- and 3-yr-old postpartum cows grazing native range. Cows were individually fed 1 of 3, 36% CP supplement treatments after parturition with increasing glucogenic potential (**GP**) supplied by RUP and PS. Supplements were isoenergetic and fed at a rate of 908 g/(cow·d) twice weekly. Supplementation was initiated 7 d after calving and continued for an average of 95 d. Supplement treatments provided: (1) 328 g of CP, 110 g of RUP + 0 g PS (**PS0**); (2) 328 g of CP, 157 g of RUP + 40 g of PS (**PS40**); or (3) 329 g of CP, 158 g of RUP + 80 g of PS (**PS80**). Ultimately, PS0, PS40, and PS80 provided 44, 93, and 124 g of glucogenic potential (GP), respectively. Body weight was recorded weekly and serum was collected twice weekly for progesterone analysis to estimate days to first estrus. Cows were exposed to bulls for 60 d or less starting mid-May. Days to first estrus exhibited a quadratic (P = 0.06) response to GP resulting from the fewest days to first estrus with the consumption of PS40. Pregnancy rates were 88, 96, 94% for PS0, PS40, and PS80 fed cows, respectively (P = 0.11). Total kilograms of calf weaned per cow exposed to bulls for the supplementation and following year quadratically increased (P = 0.09). However, supplement did not affect milk composition or yield ($P \geq 0.53$). Serum acetate half-life decreased linearly (P = 0.08) with increasing GP in 2007. Predicted margins were the greatest (quadratic; P = 0.03) for cows fed PS40. Even though supplement costs were greater for PS40 and PS80, cows fed PS40 had increased profits ($33.47/cow) over feeding cows PS0 and PS80. This study implies that young postpartum cows

fed additional glucogenic precursors may have improved reproductive efficiency and wean more calf weight per cow exposed to breeding.

Key Words: beef cows, glucogenic precursors, protein supplementation, reproduction

INTRODUCTION

Young cows grazing primarily dormant range in the semi-arid southwest experience negative energy balance during early lactation. Protein content of low quality dormant forages tends to be more limiting to grazing animal performance than energy (Wallace, 1987). Therefore, a beef cow's nutritional needs may not be met by forage alone, and thus supplementation is necessary to minimize the protein deficiency. Protein supplementation has been found to enhance intake and digestibility of dormant grass and improve cow performance (McCollum and Horn, 1990). After satisfying the RDP requirement, a MP deficiency may still exist. In that case supplemental RUP can serve to meet MP needs. Feeding additional RUP has been shown to reduce days to first estrus and BW loss (Wiley et al., 1991) and increase first-service conception rates in first-calf heifers (Triplett et al., 1995; Vasquez and Bastidas, 2005). Supplementing RUP may also alter nutrient partitioning away from lactation (Hunter and Magner, 1988) and promote synthesis of maternal tissues for maintenance, growth, and reproduction by improved energy utilization (Miner et al., 1990; Waterman et al., 2006). Waterman et al. (2006) and Endecott (2006) found that 2-and 3-yr-old cows grazing dormant rangeland and provided high-RUP supplements plus propionate salt (**PS**) had decreased days to first estrus compared with cows fed cottonseed meal-based supplements. These findings indicate that feeding high-RUP supplements plus PS will decrease days to first estrus and improve pregnancy rates in 2- and 3-yr-old cows. Therefore, the objectives of this study were to

determine the effect of increasing consumption of glucogenic precursors supplied as protein or propionate salt in range supplements on days to first estrus, pregnancy rate, BW change, and calf weaning weight.

MATERIALS AND METHODS

All animal handling and experimental procedures were in accordance with guidelines set by the New Mexico State University Institutional Animal Care and Use Committee. The study was conducted during the spring and summer for 3 consecutive years (2005 to 2007) at New Mexico State University's Corona Range and Livestock Research Center (**CRLRC**), Corona, NM. The ranch's average elevation is 2,000 m with an average precipitation of 400 mm. Rainfall during this study was 105% (2005), 76% (2006), and 117% (2007) of a 14-yr average (161 mm) for those months (Figure 1). The majority of precipitation occurs from July through September from convectional thunderstorms. Primary grass species found at the study site were blue grama (*Bouteloua gracilis*) and common wolftail (*Lycurus phleoides*) (Knox, 1998; Forbes, 1999). Pasture was 762 ha and contains approximately 355 kg/ha of standing forage (A. Cibils, New Mexico State University, personal communication). All pastures were stocked at a rate that was 50% less than the NRCS recommended rate so that forage availability was assumed not to limit cow productivity in all 3 years even with a drought in 2006 (USDA-NRCS, 2002). Three ruminally-cannulated cows were used to collect diet extrusa samples for analysis of CP (AOAC, 2000) and NDF (Van Soest et al., 1991) in 2006 and 2007. Extrusa samples were not collected in 2005 due to labor limitations. Extrusa samples were collected in April prior to breeding via ruminal evacuation techniques described by Lesperance et al. (1960). Extrusa samples from

study pasture averaged (OM basis) 5.1 and 8.1% CP, 78.6 and 85.9% NDF for 2006 and 2007, respectively.

Cows were 2 (n = 144) and 3 (n = 97) yr of age and were primarily Angus with some Hereford influence (Table 1). Management before calving was similar in all 3 yr and between age groups. At least 60 d prior to calving, cows were fed 1.6 kg/cow of a 36% CP cube once per week. Within age, cows were stratified by calving date to each supplement treatment so that age and days after calving were distributed evenly across treatments. The 2-yr-old cows were used again the following year and were reassigned randomly to treatments based on the blocking protocol. A carry over effect was not found the following year. Breeding season started mid-May in all 3 yr and was for a period of 60 d or less with a bull to cow ratio of 1:26.

Cows were assigned randomly to 1 of 3 supplements formulated to be 36% CP on an as fed basis and provided (1) 328 g of CP, 110 g of RUP + 0 g PS (**PS0**); (2) 328 g of CP, 157 g of RUP + 40 g of PS (**PS40**); or (3) 329 g of CP, 158 g of RUP + 80 g of PS (**PS80**). Ultimately, PS0, PS40, and PS80 provided 44, 93, and 124 g of glucogenic potential (GP), respectively. The additional GP contributed by supplemental RUP was calculated by using the equation of Preston and Leng (1987), where 40% of the RUP is considered to be glucogenic (Overton et al., 1999). The GP of NutroCal, which contains 80% propionate, is 95% glucogenic (Steinhour and Bauman, 1988). These values were used to calculate the added GP of supplements formulated with RUP and NutroCal. Cows were individually fed at a rate of 908 g/(cow·d) twice weekly. Supplements were formulated to be isoenergetic and were commercially cubed and milled at Hi-Pro Feeds, Friona, TX (2005 to 2006; Table 2) and Alderman Cave, Roswell, NM (2007; Table 3). Supplementation was initiated 7 d after calving and lasted for 74 (2005), 120 (2006), and 80 (2007) d postpartum. Total days of supplementation were strategically determined by

monitoring the average cow BW change of all the cows within each year. Supplementation was discontinued when total cow herd BW change was no longer negative. According to these criteria, supplementation ended 14 d into breeding in 2005 and 2007 and 7 d prior to end of breeding in 2006. Cows had ad libitum access to water and loose self-fed macro- and micro-mineral mix year long.

Cows were weighed weekly from calving until the end of breeding and again at weaning (Figure 2). Days to BW nadir were determined from the lowest BW after calving. Body weight change was evaluated between key intervals that included: beginning of supplementation to BW nadir, beginning of supplementation to the beginning of breeding, BW nadir to beginning of breeding, end of supplementation to end of breeding, and initial BW to weaning weight. Body condition scores (1 = emaciated, 9 = obese; Wagner et al., 1988) were assigned by 2 trained technicians to each cow by visual observation and palpation at initiation of the study, branding and weaning. Calf BW was recorded within 3 d after birth and again at branding and weaning. Calf branding and weaning weights were adjusted for a 55-d branding and 205-d weaning weight and no adjustments were used for sex of calf or age of dam.

Serum samples were collected twice weekly on days of supplementation (Monday and Friday) via coccygeal venipuncture (Corvac, Sherwood Medical, St. Louis, MO) beginning approximately 35 d postpartum (by cow) for analysis of progesterone to determine days to first estrus (2 or more consecutive progesterone concentrations $\geq$ 1.0 ng/mL). Blood samples were collected while cows received and consumed supplement and was centrifuged at 2,000 × g for 20 min after collection. Serum was stored and frozen (-20ºC) in plastic vials for later analysis. Serum was analyzed for progesterone concentration by solid phase RIA (Coat-A-Count, Diagnostic Products Corp., Los Angeles, CA) as described by Schneider and Hallford (1996).

Inter- and intra-assay CV were less than 10%. Cows were diagnosed pregnant by rectal palpation at weaning or a few weeks later. Open cows at weaning were then exposed to a bull for another 60 d and palpated again in the following spring. There were 2 cows fed PS80 that did not cycle during the course of the study, and after weaning were placed with a bull for another 60 d. In April, these 2 cows were palpated for pregnancy and were found to not be pregnant. These cows were then considered reproductively incompetent and were removed from the study.

Serum samples were also analyzed for insulin, glucose, NEFA, serum urea N (**SUN**), and serum IGF-I to evaluate nutrient status. Serum samples were analyzed using commercial kits for NEFA (Wako Chemicals, Richmond, VA) and SUN (Thermo Electron Corp., Waltham, MA). Glucose was analyzed with a commercial kit (enzymatic endpoint, Thermo Electron Corp., Waltham, MA). Insulin was analyzed by solid-phase RIA (Count-A-Coat, Siemens Medical Solutions Diagnostics; Los Angeles, CA) as reported by Reimers et al. (1982). Serum IGF-I samples were quantified by double antibody RIA (Berrie et al., 1995). Inter- and intra-assay CV were less than 10%. As a chute-side measure of nutrient status and glucose sufficiency, whole-blood β-hydroxybutyrate concentrations were measured (MediSense/Abbott Laboratories, Abingdon, UK, validated by Byrne et al. (2000)) in early-May during 2006 and 2007. In 2006, the same subsample (n = 29; ~ 64 d postpartum) of cows in the glucose tolerance test (GTT) were used and whole blood was taken on subsequent milking days. However, in 2007, the entire cow herd (n = 80; ~ 63 d postpartum) was used for the whole-blood β-hydroxybutyrate measurements on May 4.

A GTT was conducted in 2006 at approximately 64 d postpartum on a subsample of 2-yr-old (n = 13) and 3-yr-old (n = 16) cows to evaluate glucose half-life and sensitivity to

endogenous insulin. Cows were brought in from pasture the day of the GTT and remained unrestrained in individual pens during the course of the challenge. A 12-gauge hypodermic needle (Ideal Instruments, Schiller Park, IL) was used to puncture the jugular vein. Approximately 0.45 m of tygon tubing (0.10 cm i.d., 0.18 cm o.d., Cole-Parmer Instrument Company, Vernon Hills, IL) was threaded through the needle and into the jugular vein. The remaining portion (2.05 m) was secured with adhesive tape to the cow's neck and down the middle of the back. A blunt 18-gauge needle (Salvin Dental Specialties, Charlotte, NC) was inserted into the end of the catheter and a 10-mL syringe was used as the tubing end cap. Catheters were inserted in the morning of the GTT. A 50% dextrose solution was infused at 0.5 mL/kg BW via the indwelling jugular catheter. Blood was collected at -1, 0, 3, 6, 9, 12, 15, 20, 40, 60, 80, 100, 120, 140, 160, and 180 min relative to the infusion time. Catheters were flushed with 10 mL of a 0.9% sterile saline immediately before and after each collection time and after infusion of glucose. Sample collection time -1 min was collected before infusion of glucose and 0 min immediately after infusion. Ten-milliliter blood samples were collected at each collection time and placed in Corvac serum separator tubes (Sherwood Medical, St. Louis, MO). Serum samples were centrifuged at 2,000 × g at 4ºC for 20 min. Serum was stored in plastic vials at -20ºC for later analysis of glucose and insulin. Insulin and glucose concentrations were analyzed as previously described. Intra- and inter-assay CV for both glucose and insulin were < 10%.

In 2007, an acetate tolerance test (ATT) was conducted at approximately 64 d postpartum on a subsample of 2-yr-old (n = 12) and 3-yr-old (n = 12) cows to assess acetate clearance as affected by the GP of the experimental supplements. Catheter procedures were the same as reported for the GTT. A 20% acetic acid solution was infused at 1.25 mL/kg BW via the indwelling jugular catheter. Serum collection times were -1, 0, 1, 3, 5, 7, 10, 15, 30, 60, and 90

min relative to infusion. Infusion of acetate occurred after -1 min and before 0 min. Serum samples were collected (10 mL) at each collection time and were placed in Corvac serum separator tubes (Sherwood Medical, St. Louis, MO). Serum samples were centrifuged at 2,000 × g at 4ºC for 20 min. After centrifugation, samples were stored in plastic vials at -20º C for later analysis of acetate, insulin, and glucose concentrations.

Serum glucose and insulin concentrations were analyzed as described previously. Serum was filtered with a centrifugal filter device for 60 min at 5000 × g for deproteinization (Millipore Amicon Ultra-4 centrifugal device, Millipore Corp., Burlington, MA). Filtered serum was mixed at a 5:1 ratio with 25% metaphoshoric acid containing 2 g/L of 2-ethyl butyric acid as an internal standard. Samples, 1 μL in volume, were analyzed for acetate concentration using gas chromatography (adapted from Goetsch and Galyean (1983); Varian 3400, Walnut Creek, CA; and Supelco Nukol capillary column (30 m × 0.25 mm); temperature ramp 8º C/min from 90º C to 200º C). An internal standard was used to calculate final acetate concentrations and acetate half-life was calculated as the time required for 50% decrease in peak serum acetate concentration (Kaneko, 1989). Serum acetate, insulin, and glucose AUC were calculated using the trapezoidal summation method.

The same subsample of cows used in the glucose and acetate tolerance tests in 2006 (n = 29) and in 2007 (n = 24) were randomly selected to be an equal representation of age and treatment and were milked by a portable machine (Porta-Milker, Coburn Company, Inc., Whitewater, WI) approximately 57 d postpartum in 2006 and 69 d postpartum in 2007. Milking procedures were a modified weigh-suckle-weigh technique described by Waterman et al. (2006). Milk weights were recorded to calculate 24-hr milk production. Milk samples were analyzed for lactose, butterfat, solids non-fat, and protein by Pioneer Dairy Labs, DHIA (Artesia, NM).

An economic comparison was conducted to show predicted financial margins from each supplement from kg of calf weaned per cow exposed to breeding bulls and using treatment PS0 as the baseline. Actual postpartum feed cost was calculated for each cow with the additional yearly cost of free-choice mineral ($3.98/yr; Sawyer et al., 2005). All calves were valued at $2.20/kg at weaning. Postpartum feed cost was deducted from weaning calf value, resulting in a predicted postpartum margin ($/cow).

Statistical Analysis. Normality of data distribution and equality of variances of measurements were evaluated using PROC UNIVARIATE, the Levene test, and PROC GPLOT, respectively. Data were analyzed as a completely randomized design with cow as the experimental unit using the Kenward-Roger degrees of freedom method. The MIXED procedure (SAS Inst. Inc., Cary, NC) was used to test all main effects and all possible interactions. The model included fixed effects of supplement, cow age, year, and their interactions. Covariates were calving date and days supplemented. All interactions remained in the model regardless of significance. In addition, carryover effects were tested as covariates as described by Milliken and Johnson (1984) and were found not significant ($P = 0.54$). Preplanned contrasts were used to test for linear and quadratic effects of increasing amounts of glucogenic precursors. Serum metabolite concentrations for 2006 and 2007 were analyzed with period as the repeated factor and cow as the subject with compound symmetry as the covariance structure. The model included supplement, cow age, year, period of measurement, and associated interactions. Glucose and acetate half-lives were estimated for each animal by regressing the logarithmically transformed glucose and acetate concentrations over time (Kaneko, 1989). Area under the curve was determined for insulin, glucose, and acetate concentrations using the trapezoidal summation method. The MIXED procedure (SAS Inst. Inc., Cary, NC) was used to test all main effects of

the ATT and GTT. The model included treatment, age, and their interaction with calving date as a covariate. Economic data were analyzed with the MIXED procedure with treatment, age, year and their interactions in the model. Pregnancy rates were analyzed using logistic regression (PROC GENMOD of SAS) utilizing a model that included the fixed effects of treatment, cow age, year, and their interactions. Means for statistically significant categorical data were evaluated by generating a frequency table using PROC FREQ of SAS. Significance was determined at $P \leq 0.10$.

RESULTS AND DISCUSSION

A fundamental management element leading to greater pregnancy rates in young range cows is minimizing the length of the postpartum interval (Wiltbank et al., 1961), which allows a young cow more opportunities to conceive in a defined breeding season. Days to first estrus exhibited a quadratic ($P = 0.06$; Table 4) response resulting from the fewest days to first estrus with consumption of PS40. Waterman et al. (2006) and Endecott (2006) found similar results when young cows were fed greater quantities of glucogenic precursors and had reduced days to first estrus. An earlier return to estrus has been shown to increase the probability that conception will occur (Randel, 1990). Furthermore, the earlier a cow conceives in the breeding season, the older, heavier, and more profitable the calf will be in the following year (Wiltbank, 1970). Pregnancy rates were 88, 96, 94% for PS0, PS40, and PS80 fed cows, respectively ($P = 0.11$). Therefore, supplemental GP favorably influenced days to first estrus and tended to increase pregnancy rates even though the control supplemented cows achieved a relatively high conception rate. Fewer days to first estrus did not result in a shorter calving interval the following year ($P = 0.35$). This response was due to the fact that cows resumed estrus approximately 1 wk prior to scheduled turn out of bulls.

Cow BW was similar among supplement groups at all measurement times ($P \geq 0.28$; Table 4). Cow BW change was similar for most measurement intervals ($P \geq 0.11$). However, a quadratic ($P = 0.07$) response to the supplements was found from the beginning of supplementation to beginning of breeding with PS40 cows losing the most BW. A supplement × year interaction ($P = 0.05$; Table 5) also occurred from beginning of supplementation to the end of supplementation where the cows in 2006 lost more weight than cows in 2005 and 2007. In 2005, cows responded quadratically ($P = 0.07$) to increased GP with cows fed PS40 having the lowest BW gain. In 2007, BW gained during the supplementation period increased linearly ($P = 0.09$) with increasing GP diet.

Initial BCS (prior to calving and initiation of the experiments) exhibited a quadratic response ($P = 0.04$), resulting in cows in the PS40 group with a slightly greater condition than the other 2 supplements. After calving, BCS remained similar ($P = 0.17$) for all cows throughout the study.

Body weight nadir represents the magnitude of postpartum cow BW loss due to negative energy balance. In dairy cattle, BW nadir represents the transition from negative to positive energy balance and is considered a key management indicator for the resumption of reproductive competence (Beam and Butler, 1997). Days to BW nadir were similar among supplement groups ($P = 0.35$) and did not interact with year ($P = 0.16$). Days to BW nadir in this study were longer than reported by Endecott (2006) who reported a study using the same pastures with the same age cows, but in greater precipitation years of 2003 and 2004.

In 2006, all cows used in the GTT were considered to be insulin resistant. Supplement did not affect ($P \geq 0.19$) glucose AUC, insulin AUC or glucose half-lives (Table 6) as a result of a GTT. All cow glucose half-lives were nearly 3 times the normal half-life of 35 min as

described by Kaneko (1997). Such a metabolic state would be consistent with the effects of the drought in 2006. The lack of supplement effects on glucose half-life, glucose AUC, and insulin AUC give insight as to the severity of undernutrition experienced by the cows in 2006 with all cows having greater than normal glucose half-lives. Thus, all cows were considered insulin resistant and the increasing concentration of glucose supplied by supplements was likely used for milk production and not readily taken up by insulin sensitive tissues for weight gain and oxidative metabolism (Figure 2). Hunter and Magner (1988), Endecott (2006) and Waterman et al. (2006) suggest that improvements in serum insulin concentrations or tissue insulin sensitivity may decrease milk and milk fat yield and potentially increase BW gain, which was not found in this current study.

Serum acetate clearance can be used as an indication of GP of a diet and reveal efficiency of oxidative metabolism (Cronje et al., 1991). Additional glucogenic precursors are necessary for the efficient utilization of acetate when diets are low in protein (Cronje et al., 1991). In 2007, acetate half-life decreased linearly ($P = 0.08$; Table 7) with increasing GP. However, acetate half-life has been reported to be as rapid as 10 min (Preston and Leng, 1987), which is at approximately 3 times quicker than found in this study, suggesting that there are opportunities to further enhance oxidative metabolism. Acetate and insulin AUCs were similar ($P \geq 0.41$) among our treatment groups in 2007. However, glucose AUC decreased ($P = 0.06$) linearly with increasing amounts of GP in the diet. These data suggest that the smaller glucose AUC indicates a faster disposal rate for greater GP supplemented cows which is facilitated by a faster acetate clearance in 2007.

Whole blood β-hydroxybutyrate concentrations can accumulate in whole blood when the rate of acetate oxidation is inhibited by an inadequate supply of cellular oxaloacetate derived

from serum glucose (Kaneko, 1989). Beta-hydroxybutyrate concentrations decreased linearly (P = 0.01; Table 7) with increasing amounts of GP. These data concur with other findings that increasing amounts of dietary glucogenic precursors decreased ketone concentrations (Endecott, 2006). The increasing amount of glucogenic precursors in the PS40 and PS80 groups appear to have improved utilization of metabolizable acetate, subsequently decreasing ketone concentration, which would be expected as an outcome of increased acetate clearance rate as found in the ATT in 2007.

Twenty four-hour milk production did not differ (P = 0.26; Table 8) among supplement groups. Concentrations of milk butterfat, protein, lactose, and solids non-fat also were not influenced ($P \geq 0.14$) by increasing GP. In contrast, Waterman et al. (2006) found a 9% decrease in milk production and a 25% reduction in butterfat secretion for cows (~ 57 d postpartum) fed RUP + 100g/d propionate salt with a 54-min glucose half-life, which was 40 min faster than in the current study. Rigout et al. (2003) also found similar results to Waterman et al. (2006) with a decrease in milk fat; however, they contradicted the results of Waterman et al. (2006) by reporting that milk production increased when glucogenic precursors were either infused into the rumen or duodenum of dairy cows.

Serum urea N concentrations were similar (P = 0.59; Table 8) among the 3 supplement groups. Serum urea N concentrations of 10 to 12 mg/100 mL are usually considered optimal (Hammond et al., 1993; Stateler et al., 1995). All supplement means were below that optimum concentration. Therefore, forage protein was not in abundance and the SUN concentrations were not elevated by any of the supplements, which suggests that cows efficiently used supplemental protein even though RDP:RUP ratios varied between formulations.

Serum glucose concentrations increased linearly ($P = 0.02$) with increasing consumption of glucogenic precursors. In contrast, multiple studies have found a decrease or no increase in serum glucose with feeding increasing levels of glucogenic precursors (Cronje et al., 1991; Vanhatalo et al., 2003; Waterman et al., 2006). Despite having different serum glucose concentrations, serum insulin concentrations were similar ($P = 0.44$) between the treatments. Serum NEFA concentrations were also similar ($P = 0.13$) with increasing GP.

Insulin-like growth factor-I has been suggested to be a better indicator of rebreeding performance of first calf heifers than BCS or BW change (Roberts, 2008). Furthermore, circulating IGF-I concentration is associated with nutrient intake (McGuire et al., 1992) and is an indicator of nutrient status in dairy (Spicer et al., 1990) and beef (Roberts et al., 1997) cattle. There was a treatment × year interaction for IGF-I concentrations ($P = 0.02$; Table 9). In 2006, cows fed PS40 had the greater concentration of IGF-I than cows fed PS0 (quadratic; $P = 0.05$). However, in 2007, concentration of IGF-I was not different ($P = 0.14$) among the treatments. This interaction in IGF-I values between years may have been caused by the effects of low rainfall in 2006 compared with 2007 (Figure 1). Therefore, feeding RUP supplements with PS may exhibit a more consistent response (as shown by IGF-I) even in drought conditions and may help alleviate the negative association between drought conditions and nutrient intake.

A supplement × age interaction occurred ($P \leq 0.01$; Table 10) for calf BW at branding (adjusted 55 d of age). Increasing consumption of GP did not influence ($P = 0.24$) branding weight of calves from 2-yr-old cows. However, calves from the 3-yr-old cows fed PS80 had the lightest calves at branding than the 3-yr-old cows fed PS0 and PS40 (quadratic; $P = 0.02$). A supplement × year ($P = 0.10$; Table 11) interaction was observed for 205-d weaning weight. Differences in GP among supplements did not affect calf weaning weights in 2005 and 2006;

however, in 2007 calves weaning weights responded quadratically ($P = 0.06$) with calves from cows fed PS40 having the heaviest weaning weights.

Total kilograms of calf weaned per cow exposed to breeding bulls has been suggested to be a primary production evaluation criterion taking into account reproductive success and calf growth potential. It is the sum of the influences of the current year's conditions, milk production, and the previous year's response to conception timing, reproductive and culling rate (Ramsey et al., 2005). The number of calves weaned in relationship to the number of breeding age cows in the herd is a key indicator of efficiency. Increasing amounts of GP, in this study, decreased days to first estrus providing the opportunity to wean heavier/older calves the following year. Ramsey et al. (2005) defined ranch productivity as pounds weaned per exposed female, which integrates 3 main production variables: calving percentage, calf death loss, and breeding-season length. The importance of reproduction in young breeding females to profitability has also been demonstrated previously (Meek et al., 1999; Patterson et al., 2003). Total kilograms of calf weaned per cow exposed to breeding bulls was similar among treatment groups ($P = 0.33$; Table 4). However, total kilograms weaned for the supplemental year and the subsequent year increased (quadratic; $P = 0.09$) with increasing consumption of glucogenic potential of the diet. Over the 3 yr, predicted margins were the greatest (quadratic; $P = 0.03$) for cows fed PS40. Even though supplement costs were greater for PS40 and PS80, cows fed PS40 had increased profits ($33.47/cow) over feeding cows PS0 and PS80. Endecott (2006) found similar results of $19.42/cow increase in income when feeding RUP plus 80 g of calcium propionate compared with a traditional cottonseed meal-based supplement. Cows fed PS40 were just as reproductively efficient as the cows fed PS80, but were more cost effective. Within this

study, feeding 40 g/d of calcium propionate (PS40) is the most likely cost effective postpartum supplementation strategy.

Results of the measurement days to first estrus agree with findings of Waterman et al., (2006) and Endecott (2006). Cows fed increasing amounts of glucogenic precursors returned to estrus sooner than cows not supplemented with PS. However, supplementation with glucogenic precursors did not alter nutrient partitioning as proposed by Waterman et al. (2006) and Endecott (2006). One explanation for this discrepancy is that all cows in 2006 were insulin resistant based on GTT. Conversely, energy metabolism was improved in 2007 when cows were fed increasing amounts of glucogenic precursors. Acetate half-life, ketone concentration, and glucose AUC in 2007 decreased linearly with increasing amount of glucogenic precursors. Therefore, cows might still have been insulin insensitive; yet they were more efficient at utilizing other energy substrates such as acetate thus allowing for improved nutrient utilization. However, the conditions of 2006 and 2007 were different due to a difference in amount and timing of precipitation. Glucose tolerance test in 2006, ATT in 2007, and differences in the duration of body weight loss suggest that cows in 2007 may have been more efficient than in 2006. Finding no interactions between any reproductive measures with the main factors of supplement, age, or year suggests that potentially all supplements used had consistent effects on cow metabolism during the 3 yr independent of weight change or change in BCS. Cows fed increasing amounts of glucogenic precursors required fewer days to first estrus, with numerically greater pregnancy rates and weaned heavier calves in the subsequent year, resulting in an increased predicted income.

In conclusion, supplementing young cows with 40 g of calcium propionate provided the greatest response with decreased days to first estrus in 2- and 3-year-old range cows. Cows fed

additional glucogenic precursors appear to wean heavier calves the following year, which increased returns beyond the expense of the greater cost supplement ingredients. Diets that supply additional glucogenic precursors may decrease serum ketone concentrations and increase acetate disappearance rate indicating more efficient energy metabolism and better use of forage energy. These results indicate a more efficient overall energy metabolism and reproduction by feeding additional glucogenic precursors.

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Table 1. Distribution of 2- and 3-yr-old cows fed supplements with increasing glucogenic precursors in 2005, 2006, and 2007

Year	Cow Age	Supplement[1]			Total
		PS0	PS40	PS80	
2005	2	19	21	21	61
	3	5	8	6	19
2006	2	10	9	12	31
	3	17	19	14	50
2007	2	18	17	17	52
	3	8	10	10	28
Total		77	84	80	241

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

Table 2. Composition (as-fed basis) of protein supplements containing increasing amounts of glucogenic precursors in 2005 and 2006

	Supplement[1]		
Item	PS0	PS40	PS80
Ingredients		%	
Cottonseed meal	56.94	18.15	21.30
Urea	1.20	1.20	1.20
Wheat Middlings	21.45	40.10	32.50
Fish Meal		13.00	13.00
Hydrolyzed feather meal	0.00	12.00	12.00
Soybean Meal	10.00	--	--
NutroCal[2]	--	4.40	8.80
Molasses	9.00	9.00	9.00
Potassium chloride	0.95	2.00	2.05
Monocalcium phosphate	0.30	--	--
Vitamin A premix	0.08	0.08	0.08
Manganese sulfate	0.06	0.05	0.05
Trace mineral premix	0.02	0.02	0.02
Copper sulfate	0.01	0.01	--
Nutrient Composition			
DM	87.67	88.46	88.88
Calcium	0.24	1.58	2.42
Phosphorus	1.00	1.09	1.06
Mangesium	0.47	0.33	0.32
Potassium	2.01	2.01	2.01
Sulfur	0.36	0.37	0.37
Sodium	0.09	0.38	0.37
		ppm	
Manganese	210.49	210.57	210.71
Zinc	109.19	199.13	284.11
Iron	176.43	233.46	233.14
Copper	49.82	50.45	77.84
Selenium	0.24	0.53	0.53
Cobalt	0.44	0.38	0.38
Iodine	1.23	1.25	1.24
		1,000 IU/kg	
Vitamin A	33	33	33
		g/d	
TDN	596	590	591
CP	327	327	327
RDP	229	167	165
RUP	109	160	162

Estimated glucogenic potential	44	94	126
As fed g/d per head[3]	908	908	908

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]Source of Ca-propionate; Kemin Industries, Inc., Des Moines, IA.

[3]Total supplement individually fed at a rate of 908 g/(cow·d) twice weekly.

Table 3. Composition of protein supplements (all units as fed) containing increasing amounts of glucogenic precursors in 2007

	Supplement[1]		
Item	PS0	PS40	PS80
Ingredients		%	
Cottonseed Meal	57.82	59.46	61.31
Corn Gluten Feed	32.60	5.00	5.00
Distillers Dried Grain	--	17.79	10.71
Fish Meal	--	7.07	9.41
NutroCal[2]	--	4.41	8.81
Urea	1.39	--	--
Molasses	3.00	3.00	3.00
Calcium carbonate	2.94	1.56	--
Monocalcium phosphate	0.63	--	--
Potassium chloride	1.25	1.34	1.38
Copper sulfate	0.02	0.02	0.02
Manganous oxide	0.03	0.03	0.03
Selenium	0.10	0.10	0.10
Vitamin A premix	0.17	0.17	0.17
Trace mineral premix	0.07	0.07	0.07
Nutrient Composition			
DM	90.01	90.26	90.45
Calcium	1.50	2.00	2.36
Phosphorus	1.00	1.00	1.04
Mangesium	0.47	0.46	0.45
Potassium	2.01	2.00	2.00
Sulfur	0.53	0.43	0.42
Sodium	0.43	0.42	0.38
		ppm	
Manganese	245.87	240.94	239.68
Zinc	135.19	138.58	138.52
Iron	224.05	165.01	152.51
Copper	51.41	51.41	51.41
Selenium	0.20	0.42	0.44
Cobalt	0.07	0.07	0.07
Iodine	7.78	7.78	7.78
		1,000 IU/kg	
Vitamin A	33.03	33.03	33.03
		g/d	
TDN	613	617	587
CP	328	328	331
RDP	217	174	177

RUP	110	154	154
Estimated glucogenic potential	44	92	122
As fed g/d per head[3]	908	908	908

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]Source of Ca-propionate; Kemin Industries, Inc., Des Moines, IA.

[3]Total supplement individually fed at a rate of 908 g/(cow·d) twice weekly.

Table 4. Supplement effects on reproduction, calf and cow BW, and cow body condition for 2- and 3-yr old postpartum cows grazing native range and fed supplements with increasing glucogenic precursors in 2005, 2006, and 2007

	Supplement[1]				Contrast[2]	
Response	PS0	PS40	PS80	SEM	L	Q
Days to first estrus	77	71	74	2	0.46	0.06
Pregnancy rate, %	88	96	94	--	0.13	0.11
Ratio[3]	67/76	81/84	73/78	--	--	--
Calving interval, d	377	376	373	3	0.32	0.71
Cow BW, kg						
Begin supplementation	378	379	378	2	0.90	0.77
BW nadir	359	359	359	2	0.78	0.95
End supplementation	396	396	399	2	0.49	0.67
Begin breeding	385	383	387	2	0.65	0.28
End breeding	411	409	409	3	0.54	0.74
Weaning	446	444	448	3	0.65	0.35
Cow BW change, kg						
Begin supp - BW nadir	-32	-32	-33	2	0.63	0.90
Begin supp - begin breed	-3	-8	-3	3	0.98	0.07
BW nadir - end supp	37	35	38	2	0.71	0.32
BW nadir - begin breed	15	9	13	3	0.71	0.13
BW nadir - end breed	53	50	50	2	0.32	0.67
End supp - end breed	16	14	11	2	0.11	0.88
Initial wt - weaning wt	-7	-9	-9	3	0.69	0.83
Days to BW nadir	59	63	61	3	0.76	0.35
BCS						
Initial	4.7	4.9	4.7	0.05	0.74	0.04
Branding	4.2	4.2	4.2	0.06	0.72	0.42
Weaning	4.6	4.7	4.7	0.06	0.17	0.36
Calf BW						
Kilograms weaned per cow exposed	190	207	198	9	0.52	0.18
Two-year total weaned calf, kg	378	406	396	10	0.19	0.09
Predicted Margins, $/cow	0.00	33.47	-2.83	13.37	0.88	0.03

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]L = linear contrast; Q = quadratic contrast

[3]Ratio = number of cows pregnant/ total number of cows in treatment

Table 5. Supplement × year interaction for weight change interval for 2- and 3-yr old postpartum cows grazing native range and fed supplements with increasing glucogenic precursors in 2005, 2006, and 2007

		Supplement[1]				Contrast[2]	
Weight Change Interval	Year	PS0	PS40	PS80	SEM	L	Q
Begin of supplementation – end of supplementation, kg	2005	29	16	26	6	0.64	0.07
	2006	-16	-12	-24	6	0.22	0.18
	2007	2	4	13	5	0.09	0.59

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]L = linear contrast; Q = quadratic contrast

Table 6. Supplement effects on glucose tolerance test in 2006 for 2- and 3-yr-old postpartum cows grazing native range and fed supplements with increasing glucogenic precursors

	Supplement[1]				Contrast[2]	
Response	PS0	PS40	PS80	SEM	L	Q
Glucose tolerance test						
Glucose half-life, min	88	97	97	15	0.66	0.83
Glucose AUC	10,295	10,890	13,232	1,553	0.19	0.66
Insulin AUC	183	169	188	21	0.88	0.54

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]L = linear contrast; Q = quadratic contrast

Table 7. Supplement effects on acetate tolerance test in 2007 for 2- and 3-yr-old postpartum cows grazing native range and fed supplements with increasing glucogenic precursors

	Supplement[1]				Contrast[2]	
Response	PS0	PS40	PS80	SEM	L	Q
Acetate tolerance test						
Acetate half-life, min	35	29	27	3	0.08	0.08
Acetate AUC	247	277	247	28	0.99	0.41
Glucose AUC	9,105	8,902	7,654	515	0.06	0.42
Insulin AUC	36	34	41	7	0.63	0.57

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]L = linear contrast; Q = quadratic contrast

Table 8. Supplement effects on blood ketones, milk production, and serum metabolites for 2- and 3-yr old postpartum cows grazing native range and fed supplements with increasing glucogenic precursors in 2006 and 2007

	Supplement[1]				Contrast[2]	
Response	PS0	PS40	PS80	SEM	L	Q
Blood ketones, mmol/L						
Whole-blood βHBA[3]	0.38	0.29	0.30	0.02	0.01	0.08
Milk, g/d						
24-h milk production	5,736	6,402	5,797	463	0.93	0.26
Butterfat	179	204	169	20	0.72	0.22
Protein	145	172	155	12	0.57	0.14
Lactose	279	315	281	22	0.96	0.19
Solid non-fat	475	546	489	38	0.79	0.18
Serum Metabolites						
SUN[4], mg/100 mL	8.5	8.2	8.4	0.4	0.91	0.59
Glucose, mg/dL	54.3	55.8	57.7	1.09	0.02	0.82
Insulin, ng/mL	0.42	0.43	0.43	0.02	0.44	0.97
NEFA, mmol/L	450	481	482	15	0.13	0.42

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]L = linear contrast; Q = quadratic contrast.

[3]βHBA = β-hydroxybutyrate.

[4]SUN = serum urea N

Table 9. Supplement × year interaction for serum IGF-I of 2- and 3-yr-old cows grazing native range and fed supplements with increasing glucogenic precursors in 2006 and 2007

		Supplement[1]				Contrast[2]	
Serum Metabolite	Year	PS0	PS40	PS80	SEM	L	Q
IGF-I, ng/mL	2006	37.7	48.9	42.5	5	0.38	0.05
	2007	51.7	51.7	59.1	4	0.14	0.36

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]L = linear contrast; Q = quadratic contrast.

Table 10. Supplement × cow age interaction for calf branding weight (55 d) for 2- and 3-yr old postpartum cows grazing native range and fed supplements with increasing glucogenic precursors in 2005, 2006, and 2007

		Supplement[1]				Contrast[2]	
Measurement	Age	PS0	PS40	PS80	SEM	L	Q
Branding Weight, kg	2	63	60	64	3	0.67	0.24
	3	64	67	57	3	0.06	0.02

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]L = linear contrast; Q = quadratic contrast.

Table 11. Supplement × year interaction for calf weaning weight for 2- and 3-yr old postpartum cows grazing native range and fed supplements with increasing glucogenic precursors in 2005, 2006, and 2007

		Supplement[1]				Contrast[2]	
Measurement	Year	PS0	PS40	PS80	SEM	L	Q
205-d weaning weight, kg	2005	218	222	216	6	0.79	0.42
	2006	158	155	165	6	0.37	0.30
	2007	217	225	210	7	0.42	0.06

[1]PS0 = 0 g of Ca-propionate added; PS40 = 40 g of Ca-propionate added; PS80 = 80 g of Ca-propionate added.

[2]L = linear contrast; Q = quadratic contrast.

Figure 1. Annual precipitation (bars) by month for 2004 (year preceding study), 2005, 2006, and 2007 (years of study). Line shows 14-yr average precipitation.

Figure 2. Timeline of specific events and average weight change that occurred during the 3-yr study.

Figure 1.

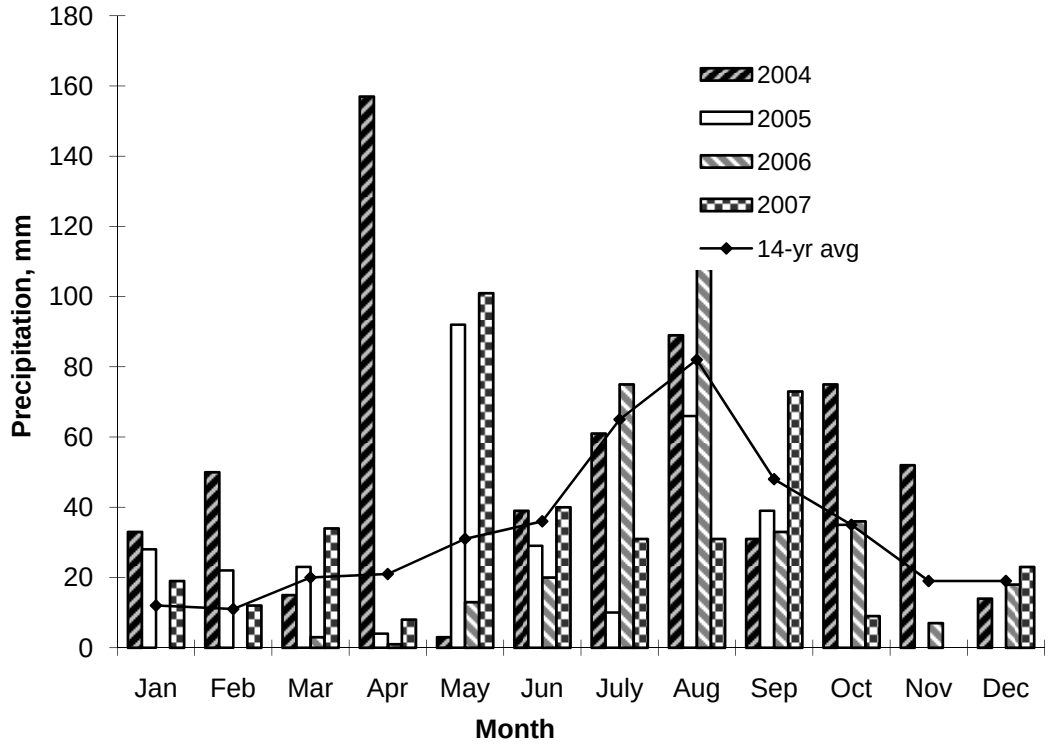

Figure 2.